

# CTDRAG

## COILED-TUBING DRAG MODEL

Version 1.0

### *User's Manual*

By

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## APPENDIX A—COMMON PROBLEMS AND SOLUTIONS



# 1. Introduction

## 1.1 BACKGROUND

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CTDRAG was developed by Maurer Engineering Inc. under sponsorship of the joint-industry project DEA-67 *To Develop and Evaluate Coiled-Tubing and Slim-Hole Technology*. This model is part of a complete coiled-tubing analysis suite, and will be incorporated into the integrated package CTPRO in the future. CTDRAG replaces the DOS-based CDRAG developed previously under DEA-67 and DEA-44 sponsorship. Many new features and capabilities have been incorporated into this advanced drag model. CTDRAG runs in the Windows environment on IBM-compatible computers with Microsoft Windows 3.x, 95 or later versions.

CTDRAG analyzes the complex phenomena of axial loads and the development of drag (and buckling) of coiled tubing as it is 1) run into the hole (slack off) or 2) pulled out of the hole (pick up). Since coiled tubing is not rotated, CTDRAG does not model torque. For compressive loads, the onset of 1) sinusoidal buckling (with a choice of three models), 2) helical buckling (with a choice of three models), and 3) pipe yielding are indicated.

Two types of axial load plots are generated:

1. Axial load vs. measured depth along the string of coiled tubing at a specific time (that is, a snapshot when the BHA is at the bottom of the hole)
2. Surface load history vs. measured depth of the BHA during slack-off and pick-up operations

All input data for the program is contained in a single project file. This file is also compatible with .SDI files (survey data input) generated by other MEI software. Survey data can be modified by the Tortuosity option, and distributed tortuosity can then be added to the survey to simulate field conditions.

## 1.2 FEATURES OF CTDRAG 1.0

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CTDRAG 1.0 is a major release in the suite of coiled-tubing software developed by MEI. Three types of coiled-tubing operations are modeled: *logging*, *drilling*, and *packer operation* (that is, generating push/pull forces downhole). Among the features are advanced buckling and drag calculations along with sensitivity analyses of each critical parameter. A special animation window displays the axial load distribution and buckling status as the coiled tubing is tripped in. A method to account for the impact of residual bending on coiled-tubing drag is included.

The “look and feel” of the program is very user-friendly and intuitive. CTDRAG runs in the Windows environment, and intuitive tabs and icons can be used to quickly navigate through the program. Input data-file management is improved, and a variety of options for customizing graphics and producing professional-style printouts are included.

Another significant feature is a complete Help system. Descriptions and instructions are provided for every input and output screen. The Help system is also context sensitive to allow intuitive navigation by pointing and clicking the mouse on the area of the screen where the user’s question originates.

## ***Chapter 1. Introduction***

Important technical features of the CTDRAG Coiled-Tubing Drag Model include:

- Handles up to eight different hole sizes and friction factors.
- Calculates both the tubing load below the stuffing box and the hook load.
- Calculates the hydraulic force caused by wellhead pressure.
- Accounts for the impact on slack-off drag of residual bending in the coiled-tubing string.
- Accounts for the weight of internal wireline.
- Wellbore survey data may be “tortured” (have doglegs added), so that the survey is more realistic than the ideal smooth trajectory resulting from well planning. The wellbore may be divided into up to five zones, with each zone given a different distributed tortuosity.
- Coiled-tubing data may be imported from a large database included with the program. Data on other tubulars may also be imported to describe the wellbore casing and production tubing.
- A sensitivity analysis allows the user to evaluate the impact of friction factor, BHA drag, wellhead pressure and WOB on drag for coiled-tubing drilling and logging operations.
- Provides a choice of systems of units, including English, SI (metric), or any user-specified custom combination.

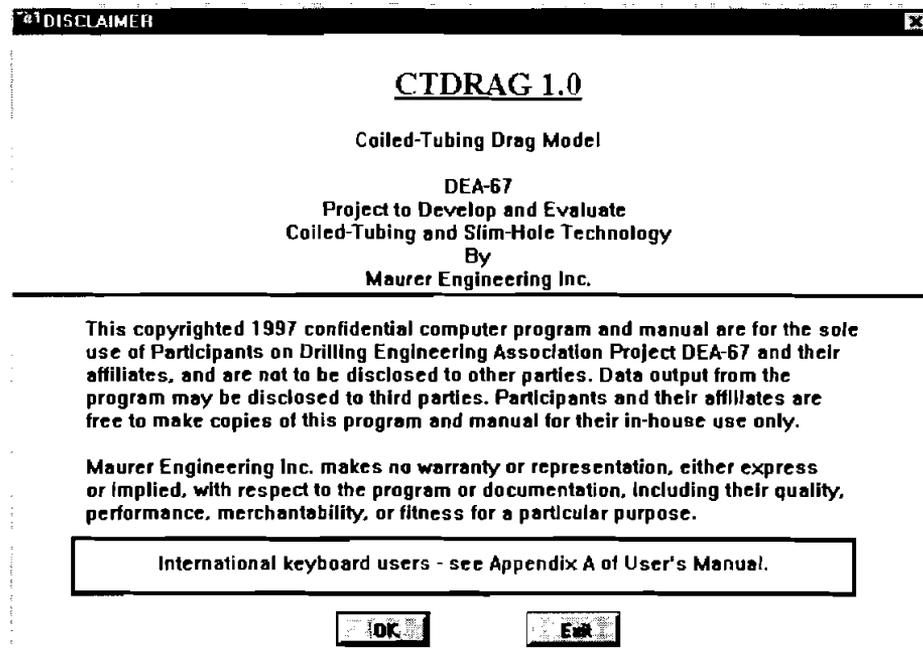
The Output Window provides a number of informative graphs and text reports including:

1. *Axial Load Distribution (Slack Off)*. This is a snapshot of loads across the string when the BHA is at the bottom of the well and slack-off (push) loads are being applied. Buckling condition is easily visualized by noting sections of the string where the axial load crosses over limit curves.
2. *Axial Load Distribution (Pick Up)*. This is a snapshot of loads across the string when the BHA is at the bottom of the well and pick-up (pull) loads are being applied. (Buckling cannot occur when the string is in tension.)
3. *Normal Force Distribution*. Normal forces (the components of compression, tension and/or gravity forces that push the string against the side of the wellbore) are plotted as a snapshot when the BHA is at the bottom of the well. Traces for both slack off and pick up are plotted together.
4. *Surface Load at Injector*. This graph shows predicted push/pull loads at the bottom of the injector throughout the planned operation.
5. *Inclination and Dogleg Angle*. The wellbore survey is illustrated with plots of both inclination angle (degrees from vertical) and dogleg angle (local rate of change of inclination).
6. *Tabulated Results*. All drag, buckling, force and survey results are summarized in a table. Columns include 1) measured depth, 2) inclination, 3) azimuth, 4) dogleg angle, 5) hook load (slack off), and 6) hook load (pick up).

All output data may be printed, copied to the Clipboard for export into other Windows applications, or stored to disk.

## 1.3 COPYRIGHT AND DISCLAIMER

This software and manual are copyrighted (©1997) by Maurer Engineering Incorporated. The copyright agreement and usage restrictions are described on the screen that immediately follows the opening title screen (see below). **By selecting OK at the bottom of this screen, the user signifies that he agrees to abide by the restrictions as presented.** No warranty or representation, either express or implied, is given with respect to this program and documentation, including their quality, performance, merchantability, or fitness for a particular purpose.



## ***Chapter 1. Introduction***

## 2. Getting Started

### 2.1 HARDWARE AND SYSTEM REQUIREMENTS

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CTDRAG is written in Microsoft Visual Basic®. It runs in either the standard or enhanced mode of Microsoft Windows 3.x or 95. The minimum hardware requirements are:

- IBM-compatible machine with 80386 processor
- Hard disk (about 3 megabytes of storage space required)
- Mouse
- VGA or compatible display

### 2.2 INSTALLING CTDRAG

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#### Program Disks

CTDRAG is shipped on three 3½-inch disks containing multiple files. We strongly recommend that all Visual Basic library files be stored in the CTDRAG subdirectory. This will avoid potential conflicts with other software based on earlier (or later) versions of the same Visual Basic library files (see Appendix A for a complete discussion). The CTDRAG executable file (**CTDRAG1.EXE**) should also be placed in the folder (default "C:\CTDRAG1", or as specified by the user) along with the example data file **Cdtest.cd1**. All of these procedures will be accomplished during the set-up procedure described below.

#### Backup Disks

It is recommended that the original disks be kept as a backup set and stored in a safe location, and that work disks be made from them. A copy of the original disks can be made using the COPY or DISKCOPY command in DOS, or "Copy Diskette" on the disk menu in the **File Manager** in Windows 3. In Windows 95, run Windows Explorer, double-click "My Computer", single-click the icon for your floppy drive, and select "Copy Disk" from the File menu.

#### Installation

The following procedure will install CTDRAG from the floppy drive onto the working directory of the hard disk (e.g., copy from A: floppy drive onto hard drive directory C:\CTDRAG1).

1. In Windows 3.x, open the Program Manager and choose **Run** from the **File** menu. Then type "A:SETUP." In Windows 95, choose **Run...** from the **Start** menu. Then type "A:SETUP."
2. Follow the on-screen instructions.

After set up, there will be a new Program Group in Windows 3.x containing the application. A new folder can be created in Windows 95 to hold CTDRAG and other MEI Applications icons. Refer to Windows 95 references for help with creating or editing folders.

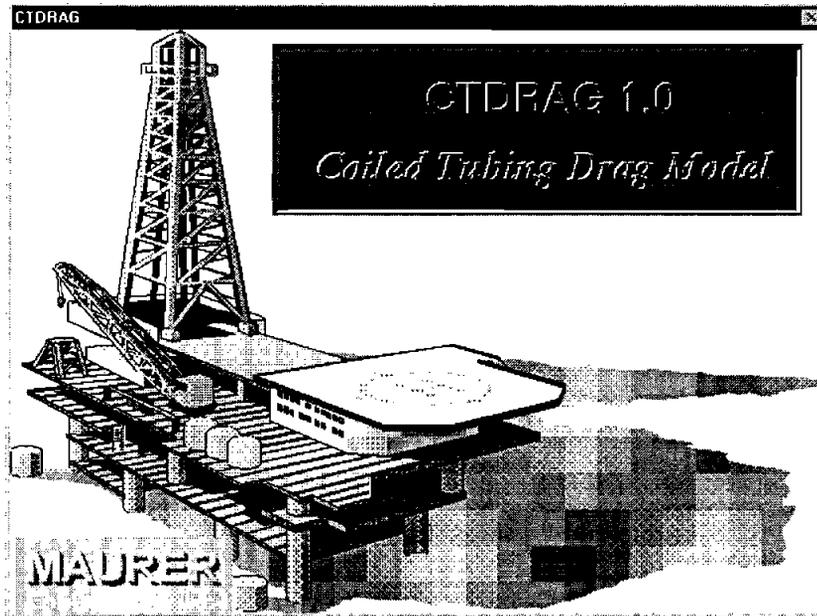
## Chapter 2. Getting Started

### 2.3 RUNNING CTDRAG

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In Windows 3.1, start CTDRAG from the MEI Applications Window. Double-click the "CTDRAG" icon, or when the icon is focused, press <ENTER>.

In Windows 95, select CTDRAG under the MEI Applications from the Program Menu.



The design and operation of the input screens in CTDRAG are described in Chapter 3. Output screens and features are discussed in Chapter 4. For assistance with the program, contact MEI using information presented in Chapter 5. Common problems and solutions are described in Appendix A.

### 2.4 QUICK TOUR OF CTDRAG 1.0

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The following quick tour will give the new user a rapid overview of the basic structure and features of CTDRAG.

#### Install:

1. Start Windows (3.1 or later version).
2. Insert CTDRAG Disk 1 in drive A:
3. Windows 3.x: choose **Run** from the File menu under Program Manager. Windows 95: choose **Run...** from the Start Menu.
4. Type **A:SETUP** and press Enter. Follow the on-screen instructions.

**Run:**

5. Launch CTDRAG. Double-click the CTDRAG icon (Windows 3.x), or select CTDRAG from the Programs list under the **Start** menu (Windows 95).
6. Click OK in the Introductory Window to accept the terms and conditions of the program license.

**Input:**

7. In the Main Window, choose “Open File...” from the **F**ile menu.
8. From the “Project File Open” dialog box, click the drive C: in the drive list box, double-click the “CTDRAG1” subdirectory (or the directory specified during set-up), click “Cdtest.cd1” in the file list box, and click OK. *(Please note that parametric values in the example project file are for illustration only and should not be considered as preferred values.)*
9. Click each of the input window tabs (**M**odel, **P**roject, **S**urvey, **T**ubulars, and **D**rag Parameters) to view each page of input data.
10. Select “Start” from the **R**un menu (or click the runner icon ). The progress of the calculation will be displayed at the bottom of the Model screen.

**Output:**

11. After the Output Window is opened, select text reports or graph windows of interest to enlarge for viewing in more detail. Click on  to zoom a graph to full screen and then  to replace the graph into the tiled windows. Double-click anywhere on the Graphs or Table to toggle between the full screen and tiled views.
12. To print the summary text report, click on the Tabulated Results window to make it active (its title bar background will turn blue) and select “Print Table” from the **F**ile menu.
13. To print a copy of any active graph window, select “Print/Graph” from the **F**ile menu.
14. Choose “Return” from the **F**ile menu to return to the input windows and then click “Exit” from the **F**ile menu to close the program.

## *Chapter 2. Getting Started*

1. The first step is to create a new project in the IDE. This is done by clicking on the "File" menu and selecting "New Project".

2. Next, you need to choose a project name and location. The IDE will prompt you for these details.

3. Once the project is created, you can start adding code to it. The IDE provides a template for a simple program.

4. You can run the program by clicking on the "Run" button. The IDE will compile and execute the code.

5. The output of the program will be displayed in the console window.

6. You can also debug the program by setting breakpoints and stepping through the code.

7. The IDE provides various tools for editing and formatting code, such as the "Format" menu and the "Code Snippets" window.

8. Finally, you can save your work and close the IDE when you are done.

## 3. Input

### 3.1 REQUIRED INPUT DATA

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Data management is very simple in CTDRAG. The filing system design in the previous program CDRAG 3 included separate files for each type of data (.WDI, .SDI, .TDI, etc.). This earlier storage design has been replaced by a single file (with extension .cd1) that stores all identification, survey, and parametric data. Wellbore survey data files used by other MEI software (in \*.SDI files) can be imported into and exported from the program. Input data required to run CTDRAG are listed below.

#### Well Information:

1. Well and project description (company name, project name, well location, etc.) (optional)

#### Survey Data:

2. Directional survey data for the well, including survey station depths, inclinations and azimuths

#### Tubular Data:

3. Description of coiled-tubing string, including OD, wall thickness, weight per unit length, whether the wall thickness is tapered, length, yield strength and Young's modulus. If the string is tapered, these data are required for each section.
4. Length, weight, ID, OD, and drag of BHA (logging or drilling)
5. Weight on bottom (drilling or packer operation)

#### Drag Parameters:

6. Depth, ID, and friction factor for each section of the wellbore
7. Additional friction factor to account for residual bending
8. Fluid densities
9. Wellhead pressure and stuffing-box drag
10. OD and weight of wireline cable inside the coiled-tubing string
11. Safety factor for applying to coiled-tubing yield load
12. Pulling capacity of coiled-tubing injector

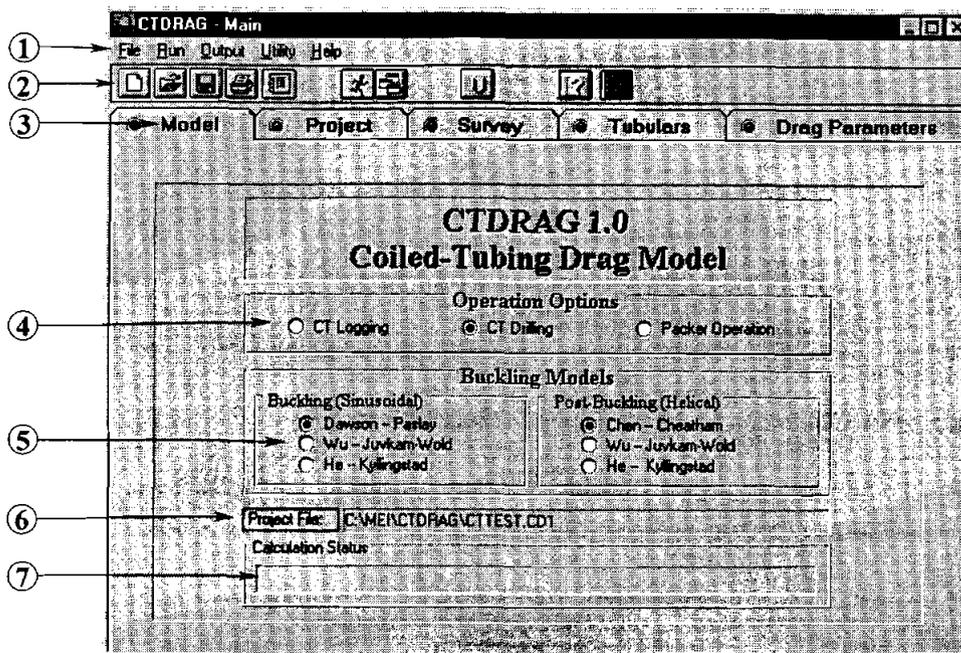
Data can be entered and displayed in English or metric units, or in a custom combination of units defined by the user. All input data saved on disk or in memory are in the English system of units.

## Chapter 3. Input

### 3.2 INPUT WINDOWS

In the Main Project Window of CTDRAG, there are five different pages for organizing input data. Each is accessed by clicking on its tab below the icon tool bar. Functions and parameters on each screen are described in the sections which follow.

#### 3.2.1 Model Page



The Model Page is the initial navigation point for controlling CTDRAG.

- ① **Menu Bar.** The function of the pull-down menus in CTDRAG is similar to that in other Windows applications. A description of all functions and features is presented later in this chapter in Section 3.2.6.
- ② **Tool Bar.** Tool bar icons can be used to quickly access commonly used functions. The icons are shortcuts for menu options. The functions of the icons are:



*New Project.* Clears all input data.



*Open File.* Activates the open file window.



*Save.* Saves all input data to the current file name. If the project is new, will automatically activate the *Save As...* window.



*Print.* Activates the print options window.



*GALAXY.* Activates the MEI GALAXY database window for importing/exporting data and results to other software.

## Chapter 3. Input



*Run.* Initiates calculations. Progress can be monitored on the Status Bar.



*Output.* Goes to output screens without recalculating. Not active if calculation has not yet been performed.



*Units.* Opens the Units Selection window. The user can select English, SI, or any custom combination of units.



*Help.* Opens the Help system for CTDRAG.



*Calculator.* Causes the Windows utility calculator to pop up.

- ③ **Page Tabs.** Switching between the five input screens for entering or checking data is simple—just click on the corresponding tab. The small circle on the left side of each tab  is like a traffic signal. A red light indicates that data entry is not complete on that page. A green light on all tabs means that all required data have been entered and that the calculation sequence may be launched.

**Note** that the tab color will not change until the page is redrawn (by selecting a different tab).

- ④ **Operation Options.** One of three basic coiled-tubing operations can be selected, including logging, drilling and operating a packer. Labels on input and output screens are activated to reflect the specific operation selected. Operations other than these three listed can be modeled by selecting the option most similar.

<i>Select...</i>	<i>for</i>
✓ <b>Logging</b>	<i>Operations without WOB (weight on bit) requirements</i>
✓ <b>Drilling</b>	<i>Operations with WOB required at a moving point downhole</i>
✓ <b>Packer</b>	<i>Operations with WOB required at a stationary point downhole</i>

- ⑤ **Buckling Models.** The user has a choice of three of the most respected models for defining sinusoidal and helical buckling criteria. A discussion on the differences in these models is presented in Section 4.3 **Interpreting Output Data.**

- ⑥ **Project File.** The project file currently in use is displayed here. CTDRAG files are automatically assigned the extension **.cd1**.

- ⑦ **Calculation Status Bar.** After the input data are entered, the calculation is launched by pulling down the run menu or clicking the run icon. Prior to beginning the calculations, the program automatically checks the data for errors (see Error Checking in Section 3.3). As the calculations are performed, the ongoing status is displayed in this bar with a percentage complete indicator.

## Chapter 3. Input

### 3.2.2 Project Page

The Project Page is used solely for project documentation. These data provide specific information about the project to identify the company, project name, well location, date, and miscellaneous comments. Any (or all) of these items may be left blank if desired. The function of the program will not be affected. The maximum string length for each entry is 60 characters.

### 3.2.3 Survey Page

	MD (m)	Inc	Azi	TVD (m)	DL (deg/30m)
1	0.0	0.00	0.00	0.0	0.00
2	304.8	0.00	0.00	304.8	0.00
3	609.6	0.00	0.00	609.6	0.00
4	914.4	0.00	0.00	914.4	0.00
5	1219.2	0.00	0.00	1219.2	0.00
6	1463.0	0.00	0.00	1463.0	0.00
7	1554.5	5.00	0.00	1554.4	1.64
8	1585.0	10.00	0.00	1584.6	4.92
9	1615.4	15.00	0.00	1614.3	4.93
10	1645.9	20.00	0.00	1643.4	4.92
11	1676.4	25.00	0.00	1671.5	4.92
12	1706.9	30.00	0.00	1698.6	4.92

## Chapter 3. Input

Survey describing the wellbore inclination and azimuth are required input. These data can be entered into CTDRAG 1) manually, 2) by pasting from an Excel spreadsheet (or other source), or 3) imported from an existing .SDI file created by another MEI program.

- ① **Survey Data Import/Export.** Wellbore survey data in CTDRAG can be easily shared with other MEI software. The standard Survey Data Input file format (\*.SDI file) is fully compatible. Data previously entered in other MEI programs can be imported into CTDRAG. Data entered into CTDRAG can be stored separately for exporting into other programs. Note, however, that the CTDRAG project file (accessed under the **F**ile menu) which stores all input data (including the survey) is **not** compatible with other programs. Data sharing requires the additional step of creating an \*.SDI file from this window.

Use the  button to clear the survey data table (i.e., new file). The  button will open an existing .SDI file for importing into CTDRAG.  will save the current survey data into the SDI format so that it can be imported into other MEI software. Again, note that this save button is not needed unless these survey data are to be used elsewhere in other software.

- ② **Survey Data Units Selection.** The user can specify the format for entering survey data based on the format of the source data. If inclination is entered in Degrees:Minutes, the data may be entered using a decimal point to separate degrees and minutes. A colon will be entered automatically.

- ③ **Survey Data Table.** Wellbore survey data are entered into the first three columns of the table. Column 1 is *Measured Depth* of the survey point. Column 2 is *Inclination Angle* at that depth. Column 3 is *Azimuth Angle* at that depth. Column 4, TVD (true vertical depth), and column 5, DL (dogleg angle) are calculated quantities. The yellow background on these columns denotes they cannot be entered or edited by the user.

The user may input up to 600 survey positions in the table. The survey depth in row 1 should be 0 feet (or 0 meters). Survey depths must be in increasing order (i.e., descending down the hole). The measured depth, inclination angle and azimuth angle each have two unit options, independent of the general system of units selected for the overall application.

### Entering/Editing the Survey Data

To enter survey data, click on the appropriate box in the spreadsheet table. The most straightforward technique for data entry is to type the number and then press <Enter>. This will automatically shift the cursor position for the next entry. The order of entry when the <Enter> key is used is:

[ROW 1] MD, Inclination, Azimuth; [ROW 2] MD, Inclination, Azimuth; [ROW 3].....

### Moving Around

When editing the data, the arrow keys are the easiest way to navigate within the table. The up/down arrow keys are used to move up or down within a single column. *To move from column to column, use the arrow keys. Do not use the Tab Key;* this will move the cursor out of the table to the next button.

## Chapter 3. Input

After the arrow key or mouse is used to move to the cell of interest, the default edit mode for that cell is the **overwrite edit mode**. Type any number or a decimal point, and the old value will be erased and replaced by the new number.

The **number edit mode** allows changing individual digits in the cell entry. This mode is activated by pressing <Escape> and then canceling the blue highlight on the cell by first using the right or left arrow. If the blue highlight is removed, single digits can be erased (using backspace or delete keys) and new digits added.

### Copying Data Into Tables

Data can easily be copied into CTDRAG from other applications (Excel, Lotus 123, etc.). This is especially convenient for survey data received from third parties (service companies). Open the data in Excel (etc.), arrange the data into the required column layout (for example, 1) *survey MD*, 2) *inclination*, 3) *azimuth*), select the data range, and copy to the Clipboard (press *Control+C*). To paste the data, open CTDRAG, place the cursor on the upper left cell of the target range, and paste from the Clipboard (press *Control+V*).

Note: set the system of units  to the format of the survey data (feet or meters) before importing. After importing, the survey can be converted to the desired units.

### Special Repeat/Copy Feature

A special feature is included in the **Survey Data Table** for copying the same value for inclination or azimuth into a range of cells. To copy a value, 1) position the cursor over the source cell, 2) click and hold the right mouse button, 3) drag the cursor down the column to the last cell to be copied into, and 4) release the right mouse button. The copy feature will not function if the source cell is activated in the edit mode by clicking on it with the left mouse button. Prior to copying, click the mouse on another cell not involved in the copy operation.

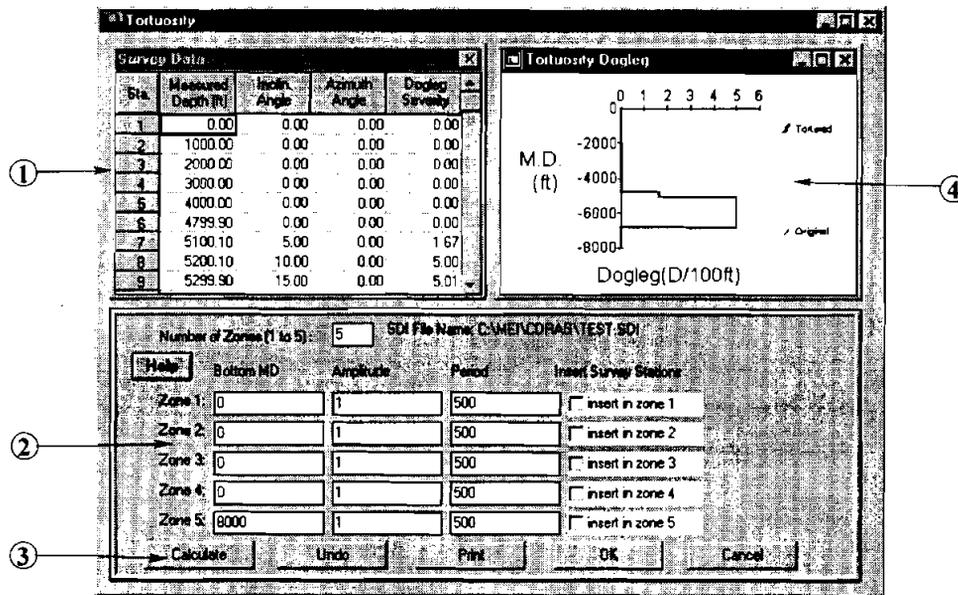
The standard Windows key combinations can also be used to copy, paste or move individual entries. *Control+C* will copy the selected entry; *Control+V* will paste; *Control+X* will remove the entry to the Clipboard.

- ④ **Data Table Control Buttons.** The table control [Insert Line] and [Delete Line] keys can be used for editing the survey table data. [Insert Line] will place a new blank row above the cursor position.  
[Delete Line] will clear the current row. A confirmation pop-up box appears before any data are deleted.
- ⑤ **Dogleg Warning Feature.** The dogleg warning feature was added at the request of our clients. If this feature is activated, the computer will beep when the dogleg severity exceeds the limit entered by the user in the box. This alarm can be used for indicating significant errors in inclination or azimuth data. Large errors (which produce large doglegs) will be quickly found and corrected.
- ⑥ **Survey Data Graph.** The survey data are plotted graphically in one of three formats chosen by the user. Options, which include inclination angle with depth, dogleg severity with depth, and a 2D wellbore profile, are selected by clicking the radio buttons at the bottom of the graph area. These plots can be very

helpful for spotting errors in the survey data. The selected graph can be sent to the printer by clicking [Print Graph].

- ⑦ **Survey Calculate Button.** When data entry is complete, the [Calculate] button must be pressed for calculating Columns 4 and 5 in the data table. These data will also be used to generate or refresh the survey graph on the right half of the screen.
- ⑧ **Tortuosity Button.** The tortuosity button activates the **Tortuosity Window** (see below).

### Tortuosity Window



When planning a well, surveys generated from geometric considerations (kick-off point, build rate, well-path shape, etc.) are usually smooth curves. Actual wells contain doglegs and other irregularities that increase drag. When ideal smooth curves are input into a drag model, the model predicts drag values that are lower than those in actual wells containing doglegs and other irregularities.

Exxon developed a simple and elegant way to modify the survey data so that conditions are more representative of real wells. Tortuosity is added to the well path; that is, a small-scale sinusoidal variation with a given period (or cycle length) is added to both inclination and azimuth angles.

The amplitude of the tortuosity (maximum value in degrees of the sine-wave variation) is chosen according to hole conditions. Exxon found that a tortuosity of  $T = 1^\circ$  represents typical field conditions. The original survey data are then modified (“tortured”) by adding the corresponding dogleg to each survey point. These data are exported to the Survey Page and used to predict drag and buckling in a non-ideal wellbore.

- ① **Survey Data Table.** The values initially appearing in this table are copied from the Survey Page. After tortuosity is added to inclination and azimuth, the adjusted values will appear in this table for review. Data cannot be edited within this table. Return to the Survey Page (click [OK] or [Cancel]) to make changes to any survey data. The table can be enlarged by using the Windows control buttons  and .

## Chapter 3. Input

- ② **Tortuosity Zone Parameters.** The survey can be divided into as many as five zones (for example: surface to KOP, first build section, first tangent section, second build section, second tangent section...). Each survey zone may then be given a different amplitude and/or period for its distributed tortuosity. The bottom measured depth should always be equal to the maximum survey depth.

**Amplitude** is the maximum dogleg added to the data. Exxon found that a tortuosity of  $T = 1^\circ$  represents typical field conditions.

The **Period** is the length of one sine-wave cycle. This value is generally greater than the distance between survey data points. Note that, in selecting the tortuosity period, one *potential problem* needs to be avoided. If the untortured survey data are equally spaced and the tortuosity period  $\Delta$  is assigned a value such that the measured depth of each survey station is  $n \cdot \Delta / 2$  (where  $n$  is any integer), then after calculation the survey data will remain untortured (the value of the tortuosity sine function will be zero exactly at every station). *This means that the tortuosity period should not be assigned a value that is  $2/n$  (2, 1,  $3/4$ ,  $1/2$ , etc.) times the distance between survey stations. It is recommended that  $\Delta$  be at least five times greater than the interval between survey stations.*

**Insert Survey Stations** is used if the survey depths are too widely spaced for a reasonable tortuosity period. Click “insert in zone x” to add stations. The default interval between inserted stations is 100 ft.

- ③ **Tortuosity Control Buttons.** There are five command buttons at the bottom of the Tortuosity Window. [Calculate] tortures the original survey data, and both the survey data table and dogleg severity graph show the tortured survey. [Undo] resets the data to the original survey. [Print] prints the active window. (If the table or graph is maximized on the screen and the print command button is hidden, press [F6] to print.) [OK] copies the tortured survey data to the Survey Page. [Cancel] closes the Tortuosity Window without any changes to the survey data.

- ④ **Tortured Dogleg Graph.** The impact of adding tortuosity to the survey can be visualized by inspecting the dogleg graph. The graph may be enlarged for easier viewing by using the Windows control buttons  and .

## 3.2.4 Tubulars Page

CTDRAG - Main

File Edit View Help

Model Project Survey Tubulars Drag Parameters

CT String Data (starting from downhole and, excluding logging tool or BHA):

	Description	OD (in)	Wall (in)	Weight (lb/ft)	True Taper	Length (ft)	Yield (psi)	Elasticity (psi)
1	section1	2.000	0.182	3.900	Yes	3000.0	70000	30000000
2	section2	2.000	0.160	3.900	No	3000.0	70000	30000000
3	section3	2.000	0.160	3.900	Yes	3000.0	70000	30000000
4	section4	2.000	0.180	3.900	Yes	3000.0	70000	30000000
5	section5	2.000	0.200	3.900	No	3000.0	70000	30000000
6								
7								
8								
Total:						15000.0		

Section Edit: Insert Delete

CT Database

CT String Display

BHA Length (ft) = 400.0  
 BHA Weight (lb) = 1221.0  
 BHA OD (in) = 2.000  
 BHA ID (in) = 1.680

BHA Drag (S-O) (lb) = 149.99  
 BHA Drag (P-U) (lb) = 0.0  
 Weight on Bit (lb) = 2000.0  
 Starting Depth of WOB (ft) = 3000.0

Total Measured Depth (ft) = 3000.0  
 CT String Plus BHA (ft) = 16400.0

- ① **CT String Data Table.** The geometry and properties of the coiled-tubing string are specified here. The element entered in the first row is the deepest section (that is, the outer end of the spool). Other tubing sections are entered proceeding toward the surface (toward the core of the spool). The cumulative length of coiled tubing is automatically calculated and displayed below the length column. Up to 20 tubing sections may be entered in the table.

**True-Taper** is a tubing option available from the manufacturers whereby the change in wall thickness between sections of a tapered string is distributed evenly throughout that entire section of tubing. (This helps minimize stress concentrations at welds.) **Elasticity** is Young's modulus, which is a material constant (30,000,000 psi for steel; 18,000,000 psi for titanium).

Techniques for entering and editing data in the table are summarized under **Survey Page - ③ Survey Data Table** in Section 3.2.3.

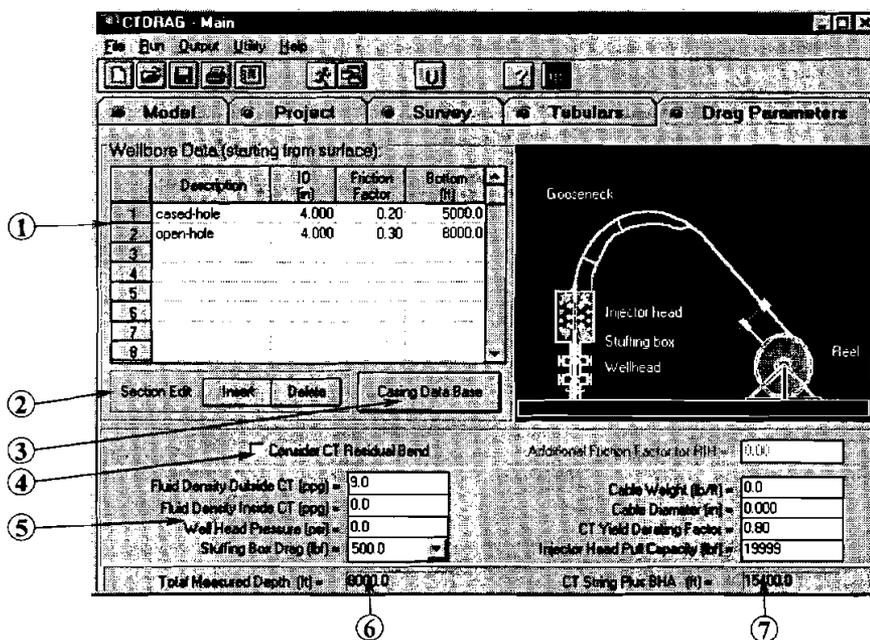
- ② **Table Control Buttons.** The control buttons for the **CT String Data Table** work only on complete rows of data. [Insert] places a new blank row above the cursor position. [Delete] clears data from one entire row, whether a single cell or whole row is selected.
- ③ **BHA Description.** The bottom-hole assembly is described in these boxes. Specific labels change depending on the analysis option selected (logging, drilling, or packer operation).
- ④ **CT Database.** If any properties of the coiled-tubing string are unknown, the user can access a large database of tubing properties. A pop-up window will request which database to load ("ctdb.db" is supplied with CTDTRAG). The database can be edited and saved under the same or another name. A row of data can be imported into the **CT String Data Table** by placing the cursor on the row and clicking [Export Data].

## Chapter 3. Input

- ⑤ **CT String Display.** The currently specified string of coiled tubing can be viewed (to relative scale) by clicking this button. A special window pops up that graphically displays the coiled-tubing outer radius and wall thickness along the entire string.
- ⑥ **Total Measured Depth.** This value is derived from the survey data and is presented here for reference.
- ⑦ **Total String Length.** The total length of the spool of coiled tubing and BHA is shown here for reference.

### 3.2.5 Drag Parameters Page

- ① **Wellbore Data Table.** Properties for each section of the wellbore are specified in this table. Up to 20



sections of casing, tubing, and open hole may be entered. A name and/or description of each section is entered in the first column (up to 60 characters). *It is important that the sections are arranged in the correct order; that is, the item at the top of the list (row 1) is the casing at the wellhead, and the remaining sections are in order descending down the wellbore.*

Techniques for entering and editing data in the table are summarized under **Survey Page - ③ Survey Data Table** in Section 3.2.3.

- ② **Wellbore Data Table Control Buttons.** The control buttons apply to complete rows of data. [Insert] places a new blank row above the cursor position. [Delete] clears data from one entire row, whether a single cell or the whole row is selected.
- ③ **Casing Data Base.** ID of casing segments can be imported from the attached casing database. The file “csgdb.db” is installed with CTDRAW, and includes data on many varieties of casing. To import casing

ID into the **Wellbore Data Table**, click the [Casing Database] button, open the appropriate file, place the cursor in any cell on the row of interest and click [OK].

- ④ **CT Residual Bend.** Coiled tubing is not completely straight as it emerges from the injector. Residual bends in the tubing can cause buckling to occur at lower axial loads than would be the case for perfectly straight tubing. The impact of residual bending can be simulated in CTDLAG by increasing the friction factor when running in the hole. Typical values for increases in friction factor due to this effect range up to about 0.05.
- ⑤ **Miscellaneous Drag Parameters.** Other parameters that impact drag and the onset of buckling are entered in these boxes. Fluid densities and wireline weight (**Cable Weight** and **Cable Diameter**) change the effective weight of the coiled-tubing string. **Stuffing Box Drag** includes a drop-down list with three entries: *no pressure*, *low pressure* and *high pressure*. These may be used as a starting point for estimating the additional injector force required to overcome drag across the stuffing box. **CT Yield Derating Factor** is applied to the yield stress limit to specify the maximum axial load allowed in field operations to avoid yielding the tubing. A value of 80% of yield (0.80) is typical.
- ⑥ **Total Measured Depth.** This value is derived from the survey data and is presented here for reference.
- ⑦ **Total String Length.** The total length of the spool of coiled tubing and BHA is shown here for reference.

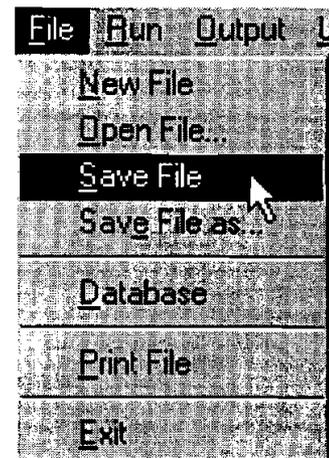
### 3.2.6 Input Window Menus

The menu system used in CTDLAG is very similar to other Windows applications. Most functions are self-explanatory. There are five menus in the Input Windows of CTDLAG: **F**ile, **R**un, **O**utput, **U**tility and **H**elp.

#### File Menu

The **F**ile menu contains commands for creating, retrieving, saving and printing input data. Users familiar with earlier MEI programs (including CDRAG) will notice a significant difference in file management with CTDLAG. Four or five files were used to store input data segregated by data type. In CTDLAG, all data are stored in a single file. (The single exception is the capability to import/export data in the standard MEI \*.SDI file format. See Section 3.2.3.) Consequently, the **F**ile menu is simplified. The functions of the individual menu options are:

1. "New File" clears all five input screens and displays a null project data file in the Model Window.
2. "Open File..." opens a dialog box for exploring the file system for input files with the extension ".cd1." This window functions as in other Windows applications.
3. "Save File" replaces the previous version of the input data file with the current modified data. No prompt is given before overwriting the previous version of the file.



## Chapter 3. Input

4. "Save File as..." saves the current version of the input data under a different name. A dialog box is opened to let the user specify the drive, directory, and name of the project file.
5. "Database" opens the GALAXY database interface window for importing/exporting data to other software.
5. "Print File" prints a form displaying all current input data and parameters.
6. "Exit" concludes the current session. CTDRAW will prompt for saving the project file if data have been changed and not yet saved.

### Run Menu

The **R**un menu is used to launch CTDRAW's calculations. Click "Start" after all input data are entered. CTDRAW will check for errors in the data (e.g., tubing wall greater than radius, etc.) prior to performing the calculations. The run icon  can also be used to launch the calculations.



The Calculation Status Bar (located at the bottom of the Model Page) will display the progress of the calculation (from 0 to 100% complete). After the calculations are completed, the Output Window displaying the results will be loaded automatically.

### Output Menu

The **O**utput menu is used to switch from the input windows to the output results window. However, since this action is performed automatically after the calculations are launched, this menu does not normally need to be accessed. This command (and the corresponding icon ) is useful, however, when the user switches back to the Main Window from the Output Window to review input data, and then wishes to return directly to the Output Window without recalculating.

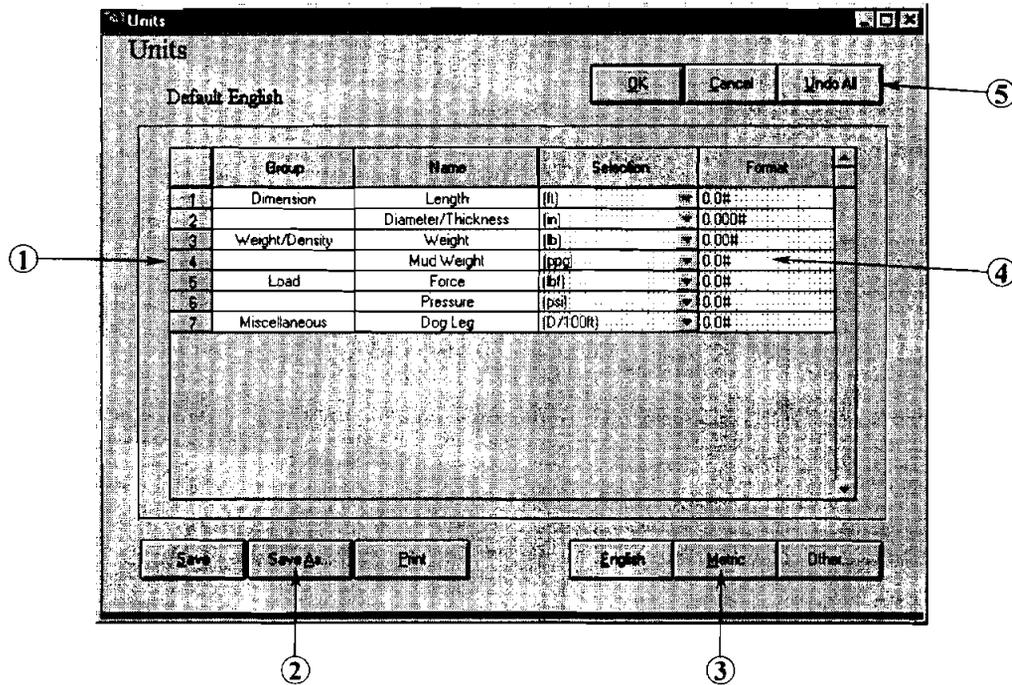


### Utility Menu

The **U**tility menu contains a command for selecting the system of units adopted for the input and output numeric boxes and graphs. Clicking "Units..." opens the.....



## System of Units Selection Window



① **Units Table.** Physical parameters and currently assigned units for each quantity are displayed in the Units Table. The user cannot edit this table directly (indicated by the yellow background). Allowable options for each quantity are accessed by pulling down the drop-down box attached to each quantity.

② **Custom Units Control Buttons.** If any changes are made to the default English or SI systems of units by selecting another option from one or more of the pull-down boxes, the new custom system will need to be saved for future use. Use the [Save] button for new custom systems or updates to previously created systems. The [Save As...] button is used when a new combination of units is designed, and the user wishes to save it separately, rather than overwriting the previous custom system. Both save buttons will cause a save dialog box to pop up. Custom systems of units are stored as \*.UNT files.

The [Print] button will print the System of Units Selection Table for documentation or reference. (This functions only after a save.)

③ **System of Units Selection Buttons.** These buttons select entire systems of units, which then appear in the table, and in all CTDRAG screens and graphs. The [Other] button will display the file names of the custom systems previously created and stored.

The name of the currently selected system of units is displayed in the upper left corner of the System of Units Selection Window ("Default English" in the figure above).

④ **Numeric Display Format Table.** The number of digits displayed for each parameter can be adjusted by the user. The number of zeroes after the decimal point for each quantity will be used as standard for the input entries and for printouts.

## Chapter 3. Input

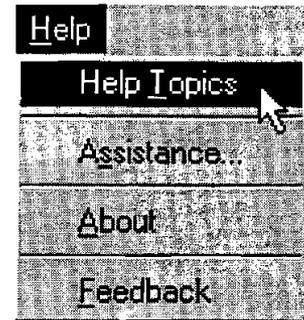
Within the decimal section of the number (which defines how many decimals are displayed), a zero denotes a “hard” digit (always displayed) and a “#” denotes a “soft” digit (displayed if required).

- ⑤ **Control Buttons.** These buttons control operations for the entire Units Selection window. [OK] accepts the current settings after any changes are made and then returns to the previous screen. [Cancel] ignores any changes made since this units screen was activated and returns to the previous screen. [Undo All] deletes all changes made since this units screen was activated, but stays in the Units window for further editing.

### Help Menu

The **Help** menu provides information for obtaining additional assistance with CTDRAG and presents various parameters describing the user’s computer.

1. “Help Topics...” launches the CTDRAG Help system.
2. “Assistance...” opens a pop-up box which displays MEI's address, phone number, e-mail address and other information. Use these contacts to obtain additional help with CTDRAG.
3. “About...” opens the About pop-up box, which displays the version number of CTDRAG along with hardware in the user’s computer.
4. “Feedback” opens a special screen form for documenting specific bugs, problems, etc. and communicating with MEI. The form can be printed for faxing or saved to disk and attached to an e-mail routed to [mei@maureng.com](mailto:mei@maureng.com).



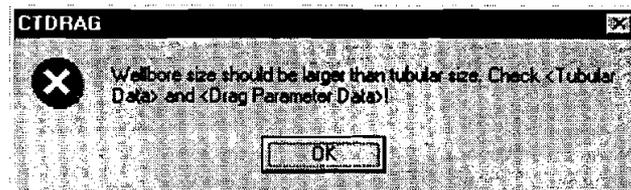
### 3.3 ERROR DETECTION FOR INPUT DATA

CTDRAG includes basic routines for detecting obvious errors in the input data. These routines are run as soon as the Run command is activated (under the **Run** menu or run icon). When input data are outside the boundaries and/or appropriate range of values, the error-checking routines will often detect the error. The program will halt calculation, display an error message describing the problem, and allow the user to correct the problem.

Obviously, CTDRAG is not capable of detecting small errors in the input data (i.e., when the incorrect parameters represent solutions that are physically reasonable), but the error checks will help prevent simple typing mistakes from having an enormous impact on the results.

If no errors are detected, the entire calculation sequence is completed for the wellbore. A calculation progress indicator is displayed at the bottom of the Model Page.

After the calculation sequence is complete, the output windows are automatically loaded.



# 4. Output

## 4.1 INTRODUCTION

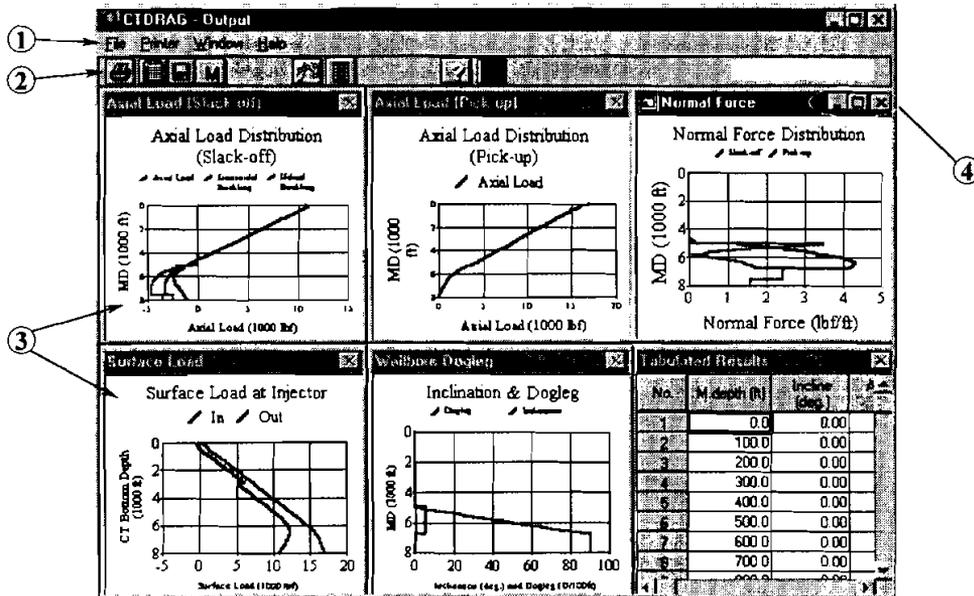
A great variety of output data is generated by CTDRAG for evaluation by the engineer. Output presentations include X-Y graphs and tables. The format of the printouts is very concise and informative. Printed output is ready for inserting into proposals, reports, etc.

The tables present numeric values of all important force and drag parameters as functions of depth. The tables generally present the same data as the graphs, and the graphical format highlights trends and trouble spots for rapid evaluation and correction. Modifications to parameters can be rapidly implemented and tested by returning to the input screen, changing any parameter(s), and recalculating.

## 4.2 OUTPUT WINDOW

The Output Window of CTDRAG is loaded immediately after the calculation sequence is completed in the Input Window. The results of the drag and buckling analyses are presented in a variety of useful graphs, as well as in tabular format. Options are provided to view the graphs individually or in groups, to copy data to the Clipboard for importing into Word, WordPerfect, Excel, PowerPoint, etc., as well as several other convenient features. Windows in the output section of CTDRAG and all corresponding functions are described in turn in the following sections.

### 4.2.1 Main Output Window



The Output Window is the central navigating point within the output section of CTDRAG. This window appears first after the calculations are completed. Six tiled windows will be displayed when the screen is first loaded.

## Chapter 4. Output

- ① **Menu Bar.** The pull-down menus in CTDRAG output are used to modify output presentation, export data, select options for graph design, and several other useful functions. A description of functions and features of the output menu is presented later in this chapter in Section 4.2.4.
- ② **Tool Bar.** Tool bar icons can be used to quickly access commonly used functions from the menus. The functions of CTDRAG's output screen icons are:



*Print.* Prints the currently focused (or maximized) graph or table.



*Copy to Clipboard.* Exports the currently focused graph or table to the Clipboard in metafile format. From the Clipboard, the data can easily be pasted into other Windows applications.



*Save.* Saves the currently focused graph or table to disk in metafile format.



*Main Window.* Returns to the main **Project Window** (i.e., the Input Window) for reviewing and/or editing input data.



*Sensitivity Analysis.* Go to the **Sensitivity Analysis** window. (See Section 4.2.2.)



*Operation Animation.* Go to the **Operation Animation** window. (See Section 4.2.3.)



*Help.* Launches the CTDRAG Help System.



*Calculator.* Pops up the Windows utility calculator.

- ③ **Graph and Table Windows.** The output from CTDRAG is presented for evaluation in six tiled windows. These include:

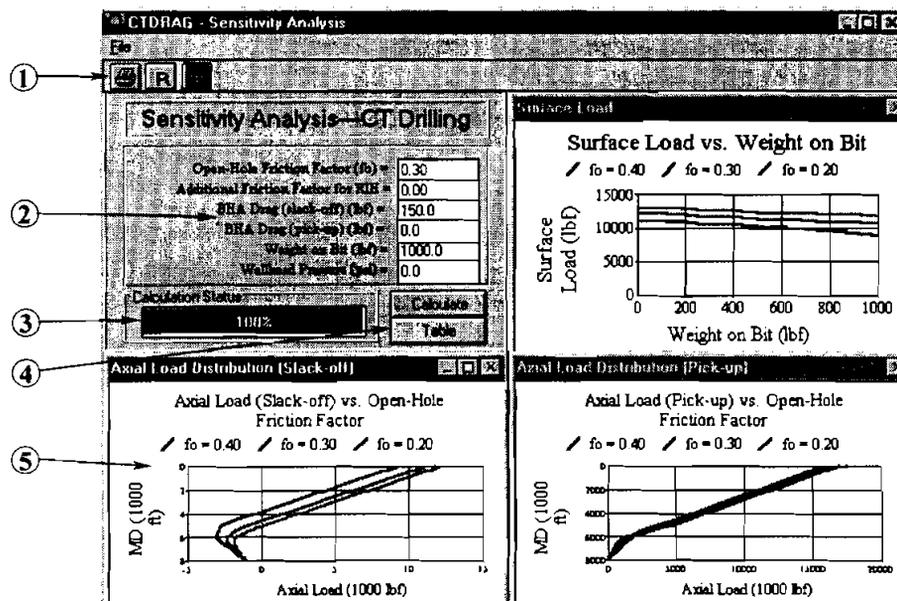
1. *Axial Load Distribution (Slack Off).* This is a snapshot of loads across the string when the BHA is at the bottom of the well and slack-off (compression) loads are being applied. Buckling conditions are easily visualized by noting sections of the string where the axial load crosses over limit curves. Curves that show yield loads (based on your safety factor) along the wellbore can be added to the graph. Maximize the plot and click  **Show Yield Limit** in the upper left corner of the graph. For operations where the working loads are significantly less than the yield/lock-up limits, deselect this option so that details of the axial and buckling curves are much easier to view and compare.
2. *Axial Load Distribution (Pick Up).* This is a snapshot of loads across the string when the BHA is at the bottom of the well and pick-up (tension) loads are being applied. The exact condition shown is when the WOB just falls to zero. The tensile load limit of the string based on the chosen safety factor can be added to the plot. Maximize the graph and click  **Show Tensile Limit** in the upper left corner of the plot. (Note that buckling cannot occur when the string is in tension.)
3. *Normal Force Distribution.* Normal forces (the components of compression, tension and/or gravity forces that push the string against the side of the wellbore) are plotted as a snapshot when the BHA is at the bottom of the well. Traces for both slack off (the BHA has just arrived at the bottom of the hole with the required WOB) and pick up (at the point when the WOB just falls to zero) are plotted together.

4. *Surface Load at Injector.* This graph shows predicted push/pull loads at the bottom of the injector (above the stuffing box) throughout the planned operation. Results can be quickly evaluated to determine whether loads during the planned operation are near limits of the equipment.
5. *Inclination and Dogleg Angle.* The wellbore survey is illustrated with plots of both inclination angle (degrees from vertical) and dogleg angle (local rate of change of inclination).
6. *Tabulated Results.* All drag, buckling, force and wellbore survey results are summarized in a table. Columns include 1) measured depth, 2) inclination, 3) azimuth, 4) dogleg angle, 5) hook load (slack off), 6) hook load (pick up), 7) sinusoidal buckling criterion, 8) helical buckling criterion, and 9) buckling condition (none, sinusoidal, or helical).

④ **Window Control Buttons.** The standard Windows 95 control buttons can be very useful for maximizing and minimizing individual graphs for rapid review and evaluation of results. The  button will enlarge a tiled graph or table to occupy the full screen. The  button will minimize a graph or plot (i.e., convert it to an icon at the bottom of the screen). The  button will temporarily turn off (close) a graph that is not of interest for a particular job operation.. After closing one or more graphs, select "Tile" from the **Window** menu to redraw the screen with only the open plots (taking advantage of the increased space for each graph). Select "All" from the **Window** menu to redraw all graphs, including those previously closed.

*An additional convenient feature* was added for rapidly reviewing the graphs. When in the tiled display format, double-click anywhere on a graph to maximize it. Review the plot, and double-click again to restore the tiled display.

## 4.2.2 Sensitivity Analysis Window



## Chapter 4. Output

The Sensitivity Analysis window is used for evaluating the effects of changes in several parameters (downhole friction factor, BHA drag, WOB, and wellhead pressure) on drag and buckling for coiled-tubing operations. This window is accessed by selecting “Sensitivity Analysis...” under the **Window** menu or by clicking the  icon.

① **Sensitivity Tool-Bar Icons.** Two icons are provided in the Sensitivity Analysis Window.



*Print.* Prints the currently focused (or maximized) graph or table.



*Return.* Closes the Sensitivity Analysis window and returns to the Output Window.



*Calculator.* Pops up the Windows utility calculator.

② **Sensitivity Analysis Parameters.** Several parameters that impact axial and surface loads can be changed independently from within the sensitivity analysis. The friction factor entered for the open-hole environment will appear on the plots as the middle of three curves. Upper and lower bounds are also generated, based on friction factors 0.10 above and below the user-designated curve. The value entered for WOB will be used for the maximum x-axis value plotted in the **Surface Load vs. Weight on Bit** plot (upper right of window).

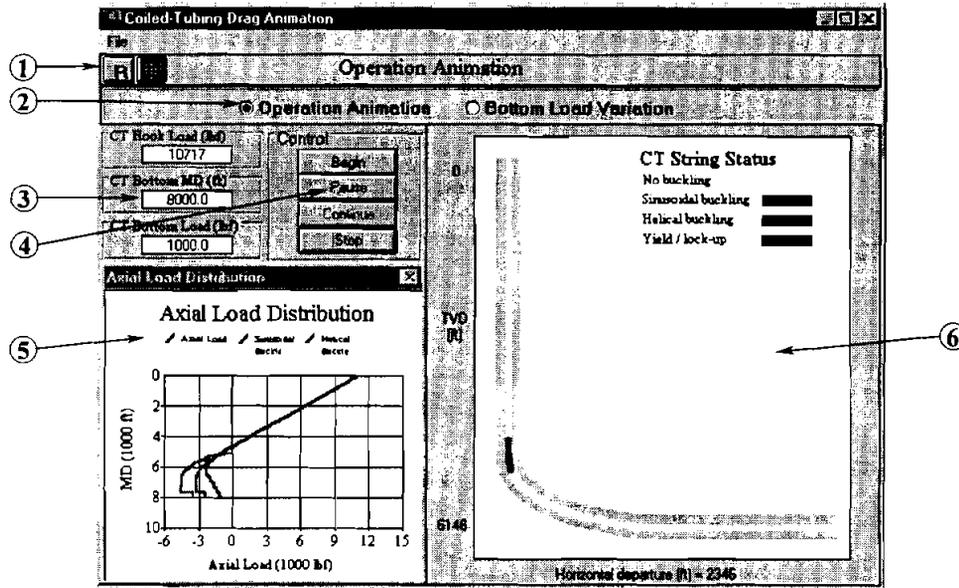
③ **Calculation Indicator.** If any parameters are changed within this window, a new calculation must be performed to generate or refresh the plots. This calculation indicator applies only to this window; results in the main **Output Window** and parameters in the **Input Window** remain unchanged.

④ **Sensitivity Analysis Control Buttons.** [Calculate] refreshes the calculation of the Sensitivity Analysis graphs and table. [Table] displays the results in a tabular format, which can be maximized, modified and printed. Press [Hide] on the table to return to the standard Sensitivity Analysis display.

⑤ **Sensitivity Analysis Graphs.** Three special graphs are presented after each set of parameters is entered and the calculations are updated. These include:

1. *Surface Load versus WOB.* Surface loads at the injector during drilling are compared for a range of friction factors. If the operation model is **Logging** (selected on Model Page), this plot is disabled since WOB is not applicable. If the model is **Packer Operation**, this plot will be entitled “Surface Load versus Packer Load.” The maximum WOB displayed is based on the user’s selection in the parameter boxes (see ② above).
2. *Axial Load (Slack-Off) versus Open-Hole Friction Factor.* Local axial loads along the coiled-tubing string (assuming the BHA is at TD) are shown for slack-off (running into the hole).
3. *Axial Load (Pick-Up) versus Open-Hole Friction Factor.* Local axial loads along the coiled-tubing string (assuming the BHA is at TD) are shown for pick-up (pulling out of the hole).

## 4.2.3 Operation Animation Window



The Operation Animation window is used to visualize and evaluate the development of buckling modes throughout the coiled-tubing operation. A second function in this window can be used to gauge the impact of increasing/decreasing weight on bottom. This window is accessed by selecting “Operation Animation...” under the **Window** menu or by clicking the  icon.

- ① **Animation Tool-Bar Icons.** Two icons are provided in the Operation Animation window.



*Return.* Closes the Operation Animation window and returns to the **Output Window**.



*Calculator.* Pops up the Windows utility calculator.

- ② **Simulation Selection.** Two types of simulations can be conducted in the Operation Animation window. **Operation Animation** will display a dynamic simulation of buckling conditions along the string as the coiled tubing is tripped into the wellbore. This simulation can be paused with the BHA anywhere along the wellbore. **Bottom Load Variation** is used to evaluate the impact of changes in the WOB (or weight on packer) on the buckling condition of the coiled-tubing string. This function can be used to determine how much reserve capacity for WOB is available before the string begins to yield (or equipment capacity is exceeded).
- ③ **Load Values.** In the **Operation Animation** mode, three boxes display the current values for the surface load (injector load), depth of the BHA, and WOB. (These parameters cannot be edited directly while in **Operation Animation** mode.) In the **Bottom Load Variation** mode, surface load, bottom load (WOB), and weight increment (the increase/decrease in WOB for every push of +/- buttons) are displayed. Bottom load and weight increment can be edited directly (as indicated by white background).

## Chapter 4. Output

- ④ **Sensitivity Analysis Control Buttons.** The animated simulation of run-in-hole operations is controlled with these buttons. [Begin] clears the data from the graphs and begins the run in with the coiled tubing at the surface. [Pause] will halt the simulation at the current depth. [Continue] is used after a pause to restart the simulation at the same depth. [Stop] is used to end the simulation at any point.
- ⑤ **Axial Load Distribution.** A special graph is displayed after each set of parameters is entered and the [Calculate] button is pressed. Axial loads and buckling criteria, all of which are updated as the simulation proceeds, are displayed for the coiled tubing up to its current depth of penetration.
- ⑥ **CT String Status.** A wellbore schematic displays the approximate well profile with current coiled-tubing depth of penetration and buckling status for all sections of the string.

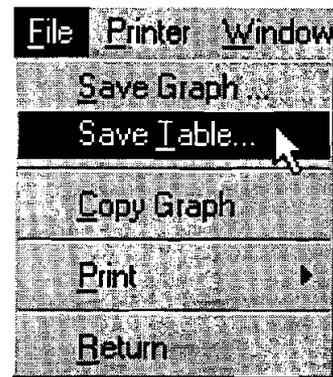
### 4.2.4 Output Window Menus

The menu system design used in CTDRAW is similar to other Windows applications. Many functions are self-explanatory. Several of the most commonly used menu functions can be easily accessed through the tool bar icons (see Section 4.2.1). There are five menus in the Output Window of CTDRAW: **F**ile, **P**rinter, **W**indow, and **H**elp.

#### File Menu

The **F**ile menu contains commands for printing, exporting, and saving output data. The functions of the individual menu options are:

1. “Save Graph...” opens a dialog box. The user specifies the drive, directory, and the name of the image file. The image of the graph is written to disk as a metafile (.WMF) or bitmap (.BMP). Select the Save File as Type in the Graph Save Window.
2. “Save Table...” opens a dialog box for saving the Tabulated Results. The user can specify the drive, directory, and the name of the image file (extension .out). The table is written to disk in ASCII format with comma delimiters.
3. “Copy Graph” copies the focused graph to the Clipboard in metafile (.WMF) format.
4. “Print...” leads to the options of “Graph”, “Table”, or “Both”, and prints a high-quality image of the graph in the currently active graph window at the full resolution of the printer. CTDRAW also offers the option of printing in color. If a color printer is available, select “color” in the **P**rinter menu. Printing in color on a monochrome printer will cause the printer to use gray scale instead of colors, and may not produce satisfactory results.
5. “Return” is used to transfer back to the Main Project Window for reviewing or modifying input data. If, after reviewing the input screens, you wish to return to the output section without making any changes to the input data, select “Go to Output Window” from the **O**utput menu or click the  icon. This saves time by not launching the calculation sequence if no data were changed.



## Printer Menu

The **Printer** menu contains commands for selecting printer options. Options include:

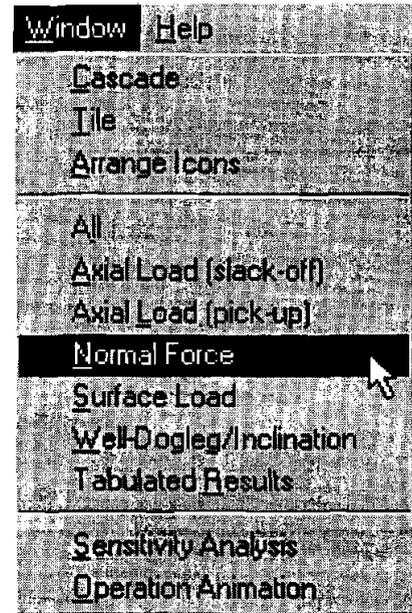


1. “Monochrome” removes colors from the graphs and switches to line thickness variation to differentiate between each data trace for any subsequent print command.
2. “Color” will send colored traces to the printer (with white background).

## Window Menu

The **Window** menu contains commands for arranging the output graphs and tables on the screen. The first four options relate to the simultaneous display of all output (i.e., all non-minimized graphs and tables).

1. “Cascade” arranges the graphs and tables in a front to back display with the title block of each graph window remaining visible. The program adjusts the size of each open window to occupy the same amount of display space. The windows are then stacked starting from the upper left corner of the Output Window. Individual plots can be pulled to the top of the stack for viewing by clicking on their title blocks or by selecting them from the list (numbers 1 through 9) in the **Window** menu.
2. “Tile” arranges the five output graphs and one table into two rows of three graphs each. This is the default arrangement when the Output Window is first loaded.
3. “Arrange Icons” restores the alignment of your report and graph window icons (used in Windows 3.x).
4. “All” and the six listed graphs and tables select the current output display. “All” shows all active plots simultaneously. Selecting an individual plot number has a different effect depending on the current display format.



*If the output screen currently is...*

*Clicking a graph or table title will display that selection as...*

A full-size maximized graph	⇒	A full-size maximized graph.
A cascaded (stacked) display	⇒	The top of the stack.
A tiled display	⇒	Unchanged, but with the focus moved.

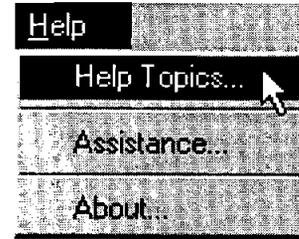
5. “Sensitivity Analysis...” pulls up the Sensitivity Analysis Window for evaluating the impact of changes in downhole and BHA parameters on axial loads and buckling. (See Section 4.2.2.)
6. “Operation Animation...” pulls up a window for evaluating the dynamic development of buckling modes throughout the coiled-tubing operation. A second function can be used to gauge the impact of increasing/decreasing weight on bottom. (See Section 4.2.3.)

## Chapter 4. Output

### Help Menu

The **Help** menu provides information for obtaining additional assistance with CTDRAG and presents various parameters describing the user's computer.

1. "Help Topics..." launches the CTDRAG Help system.
2. "Assistance..." opens a pop-up box which displays MEI's address, phone number, e-mail address and other information. Use these contacts to obtain additional help with CTDRAG.
3. "About..." opens the About pop-up box, which displays the version number of CTDRAG along with hardware in the user's computer.



## 4.3 INTERPRETING OUTPUT DATA

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Drag and buckling predictions are very useful for planning coiled-tubing operations and avoiding problems in the field. The compressive loads required to initiate sinusoidal and helical buckling are indicated on the graphic output of the slack-off plots. The tubing yield limit is also shown. The significance of these stages of buckling is described below.

### *Sinusoidal Buckling*

As compressive force is increased on a length of tubing lying along the bottom of an inclined hole, a point is reached where the tubing will assume a sinusoidal configuration side to side (basically a 2-dimensional shape) along the bottom of the hole. The critical force required to initiate this first mode of buckling is calculated in CTDRAG using one of three models selected by the user. Parameters that affect critical the sinusoidal buckling load include:

- A = Cross sectional area of tubing
- E = Young's modulus of tubing material
- g = Gravitational force
- I = Moment of inertia of tubing cross section
- r = Radial clearance between tubing and borehole
- $\rho$  = Tubing density
- inc = Inclination of hole

### *Helical Buckling*

If the compressive load is increased beyond the point where sinusoidal buckling occurs, helical buckling will eventually be initiated. In helical buckling, the tubing forms a helix (spiral) along the wall of the hole (a 3-dimensional shape like a stretched spring). The pitch of the helix decreases as the compressive load increases. Helical buckling begins when the axial compressive force is about 1.4 times the value of the sinusoidal critical load (based on the assumption of a straight hole).

## Which Buckling Criterion Do I Use?

As indicated above, the smallest critical force is the compressive load that initiates sinusoidal buckling. Next is the critical compressive force that shifts the tubing from sinusoidal to helical buckling. Finally, axial load increases to the point where the tubing begins to yield. *What is the safe upper limit for job planning?*

Field experience has been reported by several authors and participants in MEI DEA projects. Newman et al. ("Safely Exceeding the 'Critical Buckling Load' in Highly Deviated Holes," SPE 19229, 1989) indicate that coiled tubing can safely be pushed into a hole using compressive loads considerably in excess of the sinusoidal buckling threshold. In the field cases reported, compressive forces greater than the sinusoidal critical force have been used to push coiled tubing into inclined holes. Because of well geometry, they were not able to test compressive forces greater than the helical buckling critical force. It is their belief that compressive forces larger than the critical helical buckling force can safely be used to push coiled tubing into deviated holes, and many field operations conducted since then have verified this assumption.

Logging operations by Canadian Fracmaster and Esso Resources Canada (Lohuis et al., 1991: "Coiled Tubing/Production Logging in Highly Deviated and Horizontal Wellbores," CIM/AOSTRA 91-15) in British Columbia have shown that coiled tubing can be safely subjected to buckling forces considerably above the helical criterion, that is, about midway between the helical and "spring" limits (another yield criterion based on spring theory). Recent experience of at least one of the service companies indicates that the critical load calculated from spring theory is a reasonable indicator of the near upper limit of safe compressive forces to use to insert coiled tubing into deviated holes. This force is considerably larger than the force required to initiate helical buckling. It was also reported that when the spring buckling criterion was slightly exceeded, no damage to the tubing was observed.

The yield criterion is normally significantly higher than the helical buckling limit. This condition is closely associated with lock up. After the coiled tubing just begins to yield, significant additional force may be placed on the string before it fails completely, but little additional penetration will be achieved. The yield limit with an appropriate safety factor is a practical upper bound for tubing forces. The safety factor applied to the yield limit (on the **Tubulars Page**) is applied to the output graph and is based on practical experience.

Buckling criteria should be used carefully and as guides rather than as absolute indicators. Judgment based on experience, though sometimes expensive to acquire, is of great value when dealing with such concepts as buckling and all its implications. Buckling itself does not imply failure, but it indicates the onset of a condition which may precipitate failure.

## Which Buckling Model Do I Use?

Three different models for calculating sinusoidal and helical buckling loads are provided in CTDRAG. These include:

### Sinusoidal Buckling

1. Dawson/Pasley (Exxon)
2. Wu/Juvkam-Wold (Texas A&M)
3. He/Killingstad (Rogaland Research)

### Helical Buckling

1. Chen/Cheatham (Rice University)
2. Wu/Juvkam-Wold
3. He/Killingstad

A single model that has been accepted by several authors is used to calculate the load that begins to yield the coiled tubing.

## **Chapter 4. Output**

From a historical perspective, the Dawson/Paslay model was developed first and published in 1984. It quickly became widely applied. Chen/Cheatham published their model for helical buckling in 1990. The other models were developed later (Wu/Juvkam-Wold and He/Killingstad were both published in 1993) and sought to examine and improve the assumptions and boundary conditions of the earlier models.

There are two primary areas where these buckling models differ.

### ***Straight Wellbores***

For straight wellbores (for example, horizontal sections), the primary difference between the models is the nature of the changing axial load in the interval between sinusoidal and helical buckling. The assumption made by Chen/Cheatham is that the axial load between the development of sinusoidal buckling and the onset of helical buckling is constant. Since the load does actually increase between these two buckling modes, Chen/Cheatham used a constant value that is the average axial load during the helical buckling process.

Wu/Juvkam-Wold proposed that, rather than the average load, a linearly increasing load should be assumed for the helical buckling process. The result of this difference in assumptions is that Wu/Juvkam-Wold predicts a helical buckling load that is about 30% higher than Chen/Cheatham. Again, note that this applies for straight sections.

The sinusoidal buckling load in a straight hole section is the same for all three models presented in CTDRAG.

### ***Curved Wellbores***

Buckling criteria in curved wellbore sections can be significantly different depending on the model selected. The primary difference between the models is the treatment of buckling in a curved section. Tubing that is constrained in a curved wellbore is already bowed and will be supported against the bottom side of the curve. Much greater axial loads are required in this case to force the tubing to lift off the bottom of the hole and buckle. Dawson/Paslay and Chen/Cheatham do not consider the impact of curvature on the development of buckling.

Wu/Juvkam-Wold and He/Killingstad both consider the impact of wellbore curvature. Their analysis and experiments showed that, the larger the build rate, the larger the load to initiate buckling in curved wellbores with increasing inclination. Wu/Juvkam-Wold also model the increasing axial load between sinusoidal and helical buckling in curved wellbores, and consider the difference in length of the inner and outer curve of the casing. He/Killingstad assume a constant load (as did Chen/Cheatham) and ignore the length difference.

## **Comparison of Models**

Due to the differences in these assumptions of axial loads and buckling in curved wellbores, the buckling models in CTDRAG can produce different results. This is especially true for helical buckling in curved sections with increasing inclination (going to horizontal, etc.). Generally, Chen/Cheatham will produce the lowest (most conservative) helical buckling load criterion, He/Killingstad a higher load, and Wu/Juvkam-Wold the highest. In engineering analyses of this type, the engineer often tends to choose the most conservative model. However, since the constraining effect of a curved wellbore can be very significant, it is most probable that Chen/Cheatham is too conservative in these instances; that is, the string can be subjected to much higher loads without buckling helically.

Beyond buckling issues, of course, is the question of yielding the coiled tubing. The same yield criterion is used for all three models.

## 5. Getting Help

### 5.1 CONTACTING MEI

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For additional assistance with installation or operation of CTDRAG, contact:

**Dr. Roger Yan or Lee Chu  
MAURER ENGINEERING INC.  
2916 West T.C. Jester Boulevard  
Houston, Texas 77018-7098 U.S.A.**

**Telephone: (713) 683-8227  
Fax: (713) 683-6418  
E-mail: [mei@maureng.com](mailto:mei@maureng.com)**

### 5.2 REPORTING PROBLEMS

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Even though CTDRAG 1.0 has been carefully checked before its release, software bugs are a fact of life. Please report any bugs you find and describe the input parameters and conditions selected when the bug occurred. Please check Appendix A first to determine whether the solution to your problem is described there.

MEI is also very appreciative of your comments and suggestions for improving CTDRAG. Let us know if there are additional features you would like to see added to the program. Though it may not be feasible to incorporate every suggestion into the next version, many important improvements have been made to this and other MEI programs based directly on suggestions from users.

Please use the form on the next page to report bugs in the program, as well as suggestions on improving the function and usefulness of CTDRAG.

## ***Chapter 5. Getting Help***

1. Introduction

2. Getting Help

3. Getting Help

4. Getting Help

5. Getting Help

6. Getting Help

7. Getting Help

8. Getting Help

9. Getting Help

10. Getting Help

11. Getting Help

12. Getting Help

# Bug Report/Enhancement Suggestion Form

Name: \_\_\_\_\_ Company: \_\_\_\_\_  
Address: \_\_\_\_\_ City: \_\_\_\_\_ State: \_\_\_\_\_  
Phone No.: \_\_\_\_\_ Fax No.: \_\_\_\_\_  
E-mail: \_\_\_\_\_ Date: \_\_\_\_\_

Bug/Problem Report  Enhancement Suggestion

Program Name and Version Number: \_\_\_\_\_

Bug/Problem Description or Suggested Enhancement: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

Other Comments: \_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Data/Parameters Causing Bug**

Will be mailed on diskette  Will be faxed  Attached  None

**Operating System**

MS-DOS Version No.: \_\_\_\_\_ MS-Windows Version No.: \_\_\_\_\_ (Win 3.1/Win 95)  
OS2 \_\_\_\_\_ MS-Windows NT Version No.: \_\_\_\_\_  
Other \_\_\_\_\_

Please mail, fax, or e-mail to:

Lee Chu  
MAURER ENGINEERING INC.  
2916 West T.C. Jester  
Houston, TX 77018-7098  
Ph: 713/683-8227 • Fax: 713/683-6418  
E-mail: mei@maureng.com



# Appendix A — Common Problems and Solutions

Specific problems related to installing and running MEI software are described in this section. These problems have been reported by multiple users and are often related to computer settings and file locations.

## A.1 INTERNATIONAL KEYBOARD SETTINGS

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### “Type Mismatch” Error

All computer software developed at Maurer Engineering Inc. is written using the U.S. Keyboard format. Under this numeric standard, the 1000 separator is a comma, and the decimal separator is a period. Thus, the number **one thousand, two hundred and thirty-four and 22/100** is written as

1,234.22

Numbers input into MEI programs are stored in this format.

Problems have occurred for some of our clients who use the International Keyboard format, as is common in certain countries in Europe and South America. Here, the same number would be written

1.234,22

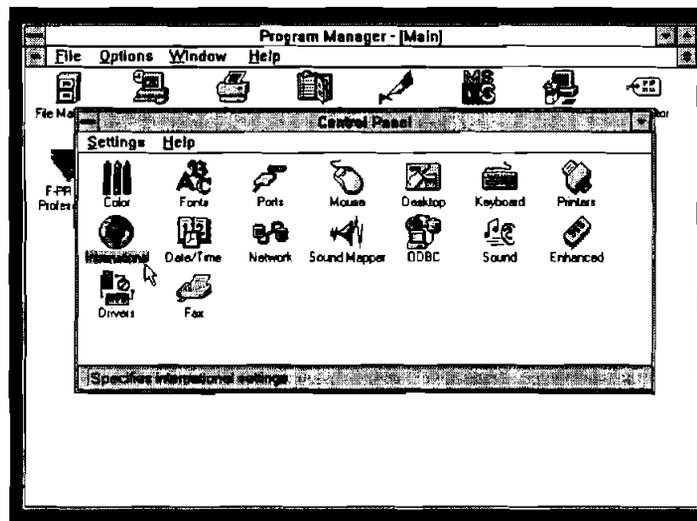
where the 1000 separator is a period, and the decimal separator is a comma.

Users with the International Keyboard format find that their computers garble input data being loaded into MEI programs. Often, a “Type Mismatch” error halts the program.

This problem can be readily solved by changing the Windows numbers format from International to U.S. format. This can be accomplished as follows:

### In Window 3.x

1. Select the “Control Panel” icon from the **Main** menu screen. This is done by pointing the mouse to this icon and double clicking. This brings up the “Control Panel” menu screen, as shown below.



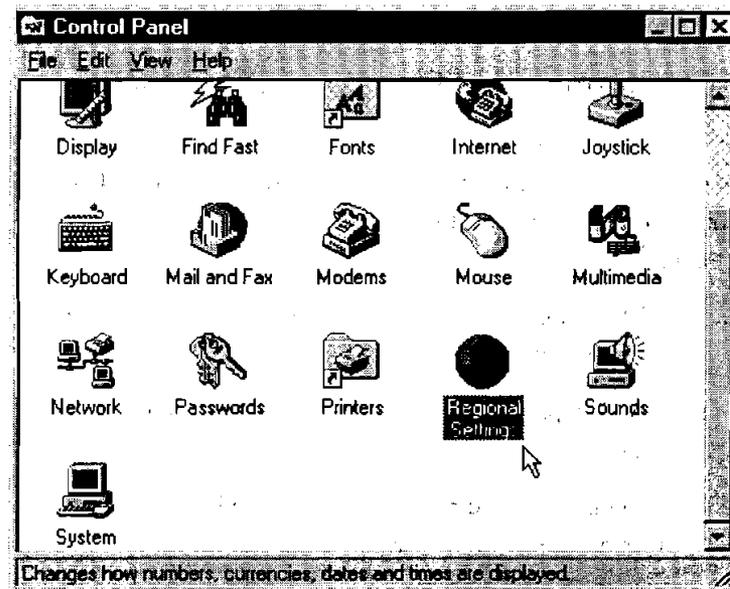
2. Select the “International” icon from this menu screen by pointing to it with the mouse and double clicking. This brings up the International Menu screen.
3. In the lower right corner of the “International” menu screen is the “Number Format.” If the number under the words “Number Format” is **1,234.22**, MEI programs should run successfully. Click <Cancel> to back out of this screen.

If the number under the words “Number Format” is **1.234,22**, it must be changed before MEI programs will run successfully.

4. To change the number format, click on the “Change” button in the “Number Format” box on the screen. This will bring up the “International—Number Format” screen. Change the “1000 Separator” from a decimal to a comma. Next, highlight the “Decimal Separator” box and erase the comma from the box and replace it with a period.
2. Click <OK> to exit the “International – Number Format” box. Click <OK> to return to the **Main** menu screen.

## In Windows 95

1. Select “Settings”→“Control Panel” from under the **Start** menu. This brings up the “Control Panel” menu screen, as shown below.



2. Double-click the “Regional Settings” icon.
3. The simplest method to change the number format is to select “English (United States)” from the drop-down list on the “Regional Settings” page. This changes all conventions to U.S. format. To change only the number format, click on the “Number” tab and change the **Decimal symbol** to “.” and the **Digit grouping symbol** to “,”. You may have to restart your computer for these changes to take effect.

## A.2 POTENTIAL LIBRARY FILE PROBLEMS

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Most of Maurer Engineering's computer programs are MS Windows-based programs which run under Windows 3.x, Windows 95, and Windows NT operating systems. When our Windows programs are run, several library files are needed (.VBX, .OCX, .DLL, and .EXE) to support the Windows interface functions. These library files might also be used by other Windows programs, which means all types of Windows applications theoretically can share the same library file from a "common library."

The basic concept of a common library is sound. Since one library file may support many programs, storing the library once in an accessible location saves space on the hard drive. However, because of compatibility issues with different versions of the same library files, the wrong library version can cause a program error. Programs developed/compiled with older versions of library files may not run with newer versions or vice versa.

When running a Windows application, Windows searches for required library files in the following sequence:

1. the `\Windows\System\` subdirectory
2. the `\Windows\` subdirectory
3. the local program subdirectory which contains the executable application .EXE file

These rules were established by Microsoft and, unfortunately, may lead to serious problems. Placing the wrong version of the common library into `\Windows\System\` subdirectory will cause all programs which use a different version of that library file(s) to malfunction. Maurer Engineering has received many reports of problems with our software after users have installed another company's software. These problems are the result of the third party software installing its own (different) version of the library into the `\Windows\System\` subdirectory. This new version then gets priority over the correct version in the local MEI subdirectory.

All MEI Windows programs install the required library into the local program subdirectory to avoid conflict with other programs already installed. Though this method requires slightly more disk space be reserved for libraries, **this is the safest approach**. If this procedure is followed, users should not be apprehensive about installing MEI's programs.

If a user finds that an MEI program will not run or the output graphs will not display, the following procedure should solve any library incompatibility problems.

1. Most of the time, MEI's programs will display an error message to indicate which library files are incompatible. If so, go to Step 4.
2. Look at the specific program's subdirectory to find all the library files needed by the program. Usually, the library file extensions are .VBX, .OCX, .DLL, .EXE.
3. Check the `\Windows\System\` and `\Windows\` subdirectories to see if there is a different version of the library file (different size or different date) stored there.
4. Move these library files from the `\Windows\System\` or `\Windows\` subdirectories to a temporary subdirectory (**do not erase these files**) to determine whether library incompatibility is the problem. If these files are used by another (non-MEI) program, copy these files to the other program's subdirectory.

The following library files most frequently cause problems: **GRAPH.VBX, GSWDLL.DLL, GSW.EXE, GSWAG16.DLL, GSW16.EXE, VBDB300.DLL, THREED.VBX, and GRID.VBX.**

If the problems persists after these steps are taken, please contact MEI.

## A.3 PRINTER SELECTION

MEI programs support a wide range of monochrome and color printers. However, most programs written in Visual Basic 3 (16-bit) do not provide options within the program for selecting individual printers. All print jobs are sent to the current Windows default printer.

### Changing Printers

If you wish to switch to a special printer, **assign that printer as the Windows default printer before running the MEI program.** The default printer is selected under the Printers control window. This window is accessed in Windows 95 by selecting **Start** → “Settings” → “Printers”. After the Printers window is open, click once on the printer of interest to highlight it. Then, select “Set as Default” from the **File** menu.

### Network Printers

Some users have experienced problems when trying to send output from MEI software to network printers. Most difficulties can be addressed by modifying the printer port entry. If a network printer will not print from an MEI program, follow these steps:

1. Select **Start** → “Settings” → “Printers”; then double-click the network printer icon.
2. Select “Properties” from the **Printer** menu. Select the “Details” tab from the Properties window (see figure).
3. Place the cursor on the entry in the text box under **Print to the following port:**. Copy the text string by pressing *control+C*.
4. Click the “Capture Printer Port...” button.
5. Select “LPT2” or “LPT3” under the **Device** pull-down menu.
6. Click the **Path:** text box; then paste the text string into the box by pressing *control+V*. Click <OK> to close the “Capture Printer Port” window.
7. On the “Details” window, pull down the list of options under the **Print to the following port:** box. Select the new entry (that you just created) with “LPT2” or “LPT3” followed by the text string copied and pasted.
8. Select <OK> and close all printer windows.

This procedure should allow printing to a network printer, provided that printer is also selected as the Windows default printer.

